Groundfish trawl nets designed to reduce the catch of Atlantic cod Gadus morhua

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Abstract

Two experimental trawl net designs substantially reduced catch rates of Atlantic cod Gadus morhua while allowing the targeting of flatfish Pleuronectidae, as compared to a standard net design. The "Ribas" and "topless" nets both modify the top half of a trawl net; the Ribas net by using large square mesh; the topless net by removing much of the netting in the top square of the net. Seventy pairs of alternate tows showed reductions of cod catch rates (kg/hr) that exceeded 76% for both nets. Catch rates of yellowtail flounder Limanda ferruginea below MLS (~33 cm TL) were more than 74% lower for both nets, compared to a standard flatfish trawl. Reductions of catch rates for winter flounder Pseudopleuronectes americanus below MLS (~33 cm TL) exceeded 61%. Significant reductions occurred in catch above MLS for yellowtail (>32%) and winter flounders (>44%) with some evidence that this reduction was lower for the topless trawl. Underwater video showed cod exiting the nets through the top mesh and through the gap made by the removal of twine. These results demonstrate that separation of Atlantic cod from flatfish is possible and practical.

Key words

trawl; Atlantic cod; flatfish; species separation; underwater video.

Introduction

A United States law, the Sustainable Fisheries Act, establishes standards for regulating the spawning stock biomass (SSB) of marine fish, including Atlantic cod Gadus morhua. Since the late 1990's, SSB estimates have led the New England Fisheries Management Council to advise the National Marine Fisheries Service (NMFS) to restrict directed cod fisheries (including trawl fisheries) and to limit landings of cod through area closures and limits on landings of cod per day and per fishing trip (NEFMC 1999; NEFSC 2000).

Alternatively, innovative fishing gear designs, in particular square mesh panels, have been used in European Community fisheries to achieve stock rebuilding targets. For example, UK Nephrops and whitefish (groundfish) fishermen have been mandated since 1991 to fit square mesh panels in all trawls or seines with mesh size less than 100 mm (Zuur *et al*. 2001). In the Baltic cod fishery, EU council regulation No. 3362/94 Article

12 (December 20, 1994) allows the use of square mesh panels in codends of trawls and seines to give a 50% retention length (L_{50}) of 38 cm (Lowry *et al*. 1995).

Area closures designed to protect cod populations prevent targeting of flatfish, some populations of which are able to support directed fisheries in New England. Landing limits and hard quotas on cod in open areas have led to substantial unmeasured capture, discard, and mortality of cod (pers. obs.) This cod mortality is demoralizing to fishermen and delays the rebuilding of the SSB, delaying easement of restrictions on fishing for cod. Closing of fishing grounds, limits on cod landings, and discard mortality of cod all represent economic loss to the fishing industry.

In New England, trawl fishermen traditionally target cod and flatfish Pleuronectidae with the same gear. However, little or no flatfish-specific gear is used or has been developed or tested locally. Results from species-selective trawl experiments conducted by the Danish Institute of Fisheries Research (reviewed by Wileman 1995) indicate that use of square mesh panels in the upper panel of a trawl at the start of the codend eases escapement of demersal roundfish while retaining flatfish. Square mesh panels, designed and fitted properly, can provide stable openings through which effective escape can occur despite changes in towing speeds, catch sizes, and other variables. (Larsen and Isaksen 1993; Robertson 1993). Square mesh panels in the codend allowed escapement of juvenile Baltic cod with low mortality (Suuronen et al.1995).

Separation of cod from flatfish has been regarded as problematic because both were thought to remain near the sea bottom when approached by a trawl. Some experiments using square mesh separation panels (Main and Sangster 1982; Engås and West 1995; Wileman 1995) indicated a high degree of species separation with cod entering the lower part of trawls, although sorting efficiencies from haul-to-haul were inconsistent (Valdermarsen et al. 1985). On the other hand, other studies were able to direct 98% of cod into an upper codend, using a horizontal separator trawl (Boudreau 1991). Prior to this study, we observed cod rising as they moved or passed over the lower belly of the net toward the codend (pers. obs.).

Net designs that exploit rising behavior of cod have included removing the front part of the upper panel and using large meshes in the upper panel of the baiting (upper square) (Main and Sangster 1981; Thomsen 1992; van Marlen 1993). Results from these studies suggested that cod were able to escape the trawl while reduction of flatfish was negligible.

The two net designs tested in this project take advantage of the rising behavior of cod in two different ways. One net, dubbed the “topless” net, eliminates as much of the top of a trawl net as possible, following a design from the Faroe Islands (Thomsen 1993). The other design, named the “Ribas” net after its designer, Capt. Luis Ribas, replaces much of the top of the net with large square mesh. These nets were compared to a standard flatfish net used by fishermen. The experimental designs mimicked the size of the standard net’s footrope, but restricted the fishing circle to 100 meshes v. 140 meshes for the standard net.

Successful testing of these nets and demonstration of their practicality was sought to allow fishermen access to areas closed due to low cod stocks. Another possible application of a net that successfully separates cod from flatfish in the Northwest Atlantic would be to reduce cod discard and mortality in open areas where groundfishing takes place through voluntary adoption by industry.

Methods

The two experimental net designs were tested against a standard design using the paired tow method (Wileman et al. 1996). Under this protocol, tows were repeated as similarly as possible in pairs, with one tow using an experimental net and the other a standard net. When possible, tow position, tow duration, and tides were duplicated, with one leg of the pair immediately following the other leg.

To allow simultaneous testing on two vessels, two standard trawl nets were constructed of 15.2 cm 3 mm diamond polyethylene (PE) mesh throughout, with 16.5-cm square knotless mesh in the codend, 25 meshes wide on the top and bottom and 50 meshes long. The headrope and footrope lengths were 12.2 and 18.3 meters (Figure 1). The fishing circle in the standard nets was 280 meshes. The Ribas (Figure 2) and topless (Figure 3) experimental nets were also constructed of 15.2-cm PE mesh with 16.5-cm square knotted mesh in the codend, 25 meshes wide on the top and bottom and 75 meshes long. The Ribas net replaced 15.2-cm diamond mesh on most of the top of the net with 20.3-cm square mesh from the headrope to the codend. The square mesh consisted of several rectangular panels sewn to pieces of diamond mesh along the selvedge. This design had a headrope and footrope length of 18.3 m. The two experimental nets had fishing circles with 200 meshes. All codends had chaffing gear on the bottom half, consisting of unbraided strands of PE twine.

The topless net has no top wings, allowing the headrope to follow a taper of the net’s gore, or selvage, into the top belly, reaching a length of 27.1 m. The bottom half of this trawl and the Ribas trawl are identical. Two sweeps (groundlines) were used during this study; a sweep with 15.2 cm cookies and a sweep with 10.2 cm cookies, used to increase flatfish catch rates.

Catch sampling was conducted by trained observers following protocols established by National Marine Fisheries Service (NMFS) and modified by the Division of Marine Fisheries (DMF) for this study. For each tow, position, time, duration, weather conditions, catch composition and weights of all species and length frequencies of target species were recorded. For some species, lengths and weights were collected separately for individuals above and below minimum landing size (MLS). In cases of large volumes, subsampling of catch and extrapolation were performed using standard DMF protocols.

Cod catch rates (kg/hr) were analyzed without regard to MLS because cod were discarded both due to size and daily catch limits. Discards of yellowtail flounder *Limanda ferruginea* and winter flounder *Pleuronectes americanus* were directly related to size. Catch rates above and below MLS were analyzed separately for these species. MLS for yellowtail flounder was 13 in TL (~33 cm); for winter flounder, MLS was 12 in TL (~30 cm). Due to non-normal distributions of data, transformations of the logarithm of the catch rate plus 1 were performed. Transformed rates were then tested first with paired t-tests, and then with ANOVA modified for unequal sample size with net and boat as factors (Sokal and Rohlf 1995). Tukey's b method was next used to find significant differences in converted means, if any.

Total lengths of cod and commercially valuable flatfish were collected to the nearest centimeter; often all individuals caught were measured. For each net type, these lengths were combined across all tows. When subsamples were measured or when kept and discarded fish were measured separately, the total estimated number of individuals (N) at each length was extrapolated from the proportion of the subsample to the total catch. These lengths were compared between experimental and controlled tests using the Kolmogorov-Smirnov tests, adjusted for sample sizes (Sprent 1989; Sokal and Rohlf 1995). Standard fishing practices were followed as much as possible. Fishing locations were selected to optimize catches of cod and flatfish.

Underwater video of cod and flatfish behavior was acquired with a third-wire pan-and-tilt system developed by DMF (Carr and Milliken 1998). The camera was mounted on the headrope of the experimental nets. The pan-and-tilt unit has a 360-degree range of motion, allowing an ondeck operator to point the camera in a useful direction. Cod and flatfish reactions were logged and classified into two basic categories: fish that escaped and fish that are caught in the net. Flatfish species could not be distinguished due to inadequate video resolution and were grouped together.

Results

Seventy pairs of tows and two days of underwater filming were completed between December 2000 and May 2002 and included in analyses (Table 1). Fifty-nine tows were conducted and excluded due to inadequate pairing, gear damage, or other factors. Tows were conducted near Provincetown, Massachusetts USA on Stellwagen Bank and other nearby grounds (Figure 4). Thirty-four pairs were accomplished with the Ribas net; thirty-six with the topless net. Three commercial fishing vessels were used: Blue Skies (272 kW, 19 m LOA) and Blue Ocean (271 kW, 19 m) of Provincetown; Dolores Louise (248 kW, 14 m LOA) of Gloucester, Massachusetts.

For all 199 tows combined, the primary species caught and kept were yellowtail flounder (35,859 kg) and winter flounder (7,428 kg). Primary discards included: skates Rajidae (35,858 kg); yellowtail flounder (6,644 kg); ocean pout Macrozoarces americanus (4,217 kg); sculpins Myoxocephalidae (2,812 kg). Approximately 17,150 kg of Atlantic cod (kept and discarded combined) were caught during testing. A total of 129,055 kg of fish and shellfish from 34 taxa were caught overall.

Catch rates of cod, yellowtail flounder, and winter flounder were highly variable and were log-transformed. Paired t-tests on log-transformed catch rates indicated significant reductions by both experimental nets in cod catches (Table 2). Results from the paired tows showed lower cod catch rates with both the Ribas net (71.5% less; $p = 0.00$) and the topless net (86.9% less; $p = 0.00$). The catch rates of yellowtail flounder above MLS were also lower in the Ribas net (37.7% less; $p = 0.00$) and the topless net (32.0% less; $p = 0.00$). Yellowtail flounder below MLS showed even higher differences in catch rates between the standard net and the experimental nets ((Ribas: 74.87% less; $p = 0.00$)(topless: 81.2% less; $p = 0.00$). Winter flounder above and below MLS also had significantly lower catch rates in both experimental nets compared to the standard net (Ribas: >MLS, 55.7% less; <MLS, 82.2% less; $p = 0.00$) (topless: >MLS, 44.7% less; <MLS 60.6% less; $p = 0.00$).

Visual comparisons of the transformed catch rates reinforced the results of the paired t-tests. Catch rates of pairs of tows were used as XY coordinates and plotted. An equal catch line was added as a null hypothesis (catch rates are identical) comparison. Of the seventy pairs of tows testing the two experimental nets compared to the standard design, 30 of the 34 pairs of Ribas net tests and 33 pairs of 36 pairs of topless net tests yielded lower cod catch rates for the experimental designs (Figure 5A). Results for yellowtail above MLS showed 55 pairs of tows (28 Ribas, 27 topless) where the experimental nets had higher catch rates than the standard net, although in general more pairs of tows were close to the equal catch line than for the cod comparison (Figure 5B). Sixty-six of seventy pairs (32 Ribas, 34 topless) had lower catch rates of yellowtail flounder below MLS in the experimental nets (Figure 6A). Fifty-eight pairs of tows (28 Ribas, 30 topless) caught more winter flounder above MLS in experimental nets than the standard net (Figure 6B).

The effect of the different vessels used in the testing on these results was evaluated using a two-way ANOVA of catch rates using vessel and net as factors. For cod, a vessel effect ($F_{2, 140} = 12.35$; $p = 0.000$) and a net effect ($F_{2,140} = 12.57$; $p = .000$) were significant, but their interaction (net x vessel) was not ($F_{4, 140} = 0.852$; $p = 0.495$). Tukey's b test indicated that the mean catch rates for both experimental nets were significantly different ($p = 0.05$) from the standard design.

ANOVA results for yellowtail flounder above MLS also were significant for net effect ($F_{2, 140} = 4.64$; $p = 0.011$) but not for boat effect ($F_{2, 140} = 0.318$; $p = 0.728$). Vessel-net interaction was also not significant ($F_{4, 140} = 0.587$; $p = 0.672$). Tukey's b test indicated that the catch rates of yellowtail flounder above MLS for the Ribas net were significantly lower ($p = 0.05$) than the standard; the standard net and the topless net performed similarly.

ANOVA of catch rates of yellowtail flounder below MLS found that the vessel effect ($F_{2, 140} = 6.767$; $p = 0.002$) and the effect of the nets ($F_{2, 140} = 21.469$; $p = 0.000$) were significant, but the interaction effect was not ($F_{4, 140} = 0.875$; $p = 0.481$). Tukey's b indicated that both experimental nets caught smaller flounder at lower rates than the standard nets ($p = 0.05$).

Results of analysis of winter flounder above MLS showed that both vessel ($F_{2,\,140} = 3.668$; $p = 0.028$) and net type ($F_{2,\,140} = 3.532$; $p = 0.32$) explained much of the variance in catch rates, but vessel- net interaction did not ($F_{4,\,140} = 0.817$; $p = 0.517$). Tukey’s b results provided evidence that the topless net caught winter flounder at rates similar to the standard design, and that the Ribas net caught fewer flounder above MLS ($p = 0.05$).

ANOVA results for vessel effect for winter flounder below MLS showed a significance level above 0.05 ($F_{2,\,140} = 2.632$; $p = 0.076$). The effects of the different nets were significant ($F_{2,\,140} = 7.992$; $p = 0.001$); net-vessel interaction was not ($F_{4,\,140} = 0.823$; $p = 0.513$). Tukey’s b showed that both experimental nets had catch rates lower than the standard net ($p = 0.05$).

Length-frequencies of fish were analyzed to determine whether the nets affected different sized fish differently. The size distributions of cod, yellowtail flounder, and winter flounder were all different in the standard and experimental codends. The Ribas design and the standard net caught different sizes of cod (KS = 0.27, p = 0.00, N = 1876, 435) (Figure 7A). The topless net cod distribution was also significantly different from the distribution in the standard net (KS = 0.29; p = 0.00, N = 1694, 220) (Table 5) (Figure 7B).

Length-frequency distributions of yellowtail flounder were significantly different between the standard net and the Ribas design (KS = 0.26; p = 0.00; N = 22761, 9313). The Ribas net caught few small (<30 cm) yellowtail flounder (Figure 8A). Length distributions of yellowtail flounder between the standard net and the topless net were also significant (KS = 0.29; p = 0.00; N = 28940, 15089). The topless net caught few fish below 33 cm, and more larger fish 41-50 cm (Figure 8B).

The length distributions of winter flounder caught in the Ribas net were significantly different from the lengths of winter flounder caught in the standard net (KS = 0.185; p = 0.00; N = 4600, 1382). The topless net lengths were also significantly different from those caught in the standard net tows (KS = 0.26; p = 0.00; N = 4158, 1912). The standard net caught greater amounts of smaller (< 32 cm or ~13 in) flounder. The modes of both experimental nets were higher than the standard nets (Figure 9A, 9B).

Video footage was collected on 4 December, 2000 and 5 January, 2001. Fish behavior was not quantitatively assessed, but several tendencies were observed. For the Ribas net, most of the cod reacted similarly when first encountering the net, swimming low near the footrope. As they tired or moved further back into the net, fish rose up into the upper half of the trawl (above a visible sand cloud) and fell back into the net. Fish that went over the headrope either rose very quickly or were initially swimming higher in the mouth of the net. Two cod were observed escaping through the meshes in the upper half of the trawl (Table 3).

Flounder all seemed to exhibit similar behavior with regard to this net. They swam in short bursts in front of the footrope and then appeared to tire quickly and tumbled back into the net. They typically stayed close to the lower belly meshes as they fell into the net. Very few flounder tried to escape under the sweep when it bounced off the seafloor. In a few instances, flounder gave a strong burst of speed and swam up higher, but were caught in the net.

More cod were observed to go over the headrope of the topless net than fish that fell back into the net, as expected. Fish that were in front of the footrope could not be seen, because the headrope (where the camera was mounted) was far back from the front of the net or because of sand clouds. Fish could only be seen when they were either above the sand clouds or directly in front of the camera. In a few instances, cod swam in one burst over the net or into the net.

It was difficult to determine if flounders escaped under the sweep because of the camera position. More flounder that got caught in the net were located in the sand cloud along the lower belly meshes than in other parts of the net. Some flounder near the wing-ends were caught as they appeared to tire and were pushed down the net. A few flounder skipped over the headrope near the wing-ends (Table 3).

Discussion

Reductions in cod catches were substantial and dramatic with the experimental nets, providing strong evidence that the alterations in design allowed cod to escape through rising behavior. Further, both innovative trawls reduced cod catches proportionally higher than the reduction in flatfish catches. Additionally, substantial reductions in catches of yellowtail and winter flounders below MLS were accomplished. While some loss of marketable fish was observed, both experimental designs were highly effective in avoiding cod and small flatfish.

Underwater video provided evidence that cod were escaping either through large square meshes on the top or by rising through the space that would typically be occupied by meshes in the top of the net. These results may contradict other findings that used the rising ability of haddock to separate cod and haddock Melanogrammus aeglefinus (Engås and West 1995). This contradiction might be explained by differential rising rates: that haddock rise quickly, and cod more slowly. Also, differences in headrope heights may explain different researchers' conclusions about rising behaviors. In this study, headrope height was less than 2 m, so cod would not need to rise far to escape these experimental nets. Headrope heights of haddock nets can be much higher.

Reactions of Atlantic cod may differ between stocks or geographical locations. Speed of movement of fish, and ability to penetrate cod end meshes is linked to temperature (Ozbilgin and Wardle 2002); temperature differences between regions and studies might explain the differing results. In either case, investigations of differing behaviors between stocks, and between species, would be enhanced by the determination of quantitative measures of behaviors, such as rising rates. In the Northwest Atlantic, exploitable haddock stocks that commingle with cod stocks provide a strong incentive for uncovering differences in their behaviors.

Wardle (1993) suggested that the visual perception of the headrope causes fish to rise. However, video observations of the topless net, with a headrope far behind the footrope, indicated that cod were rising much earlier than the headrope could be perceived. While rising may be a result of perception of the footrope, it appears that cod rose to avoid a sand cloud produced by the doors, tickler chain, or other ground gear. Cod might avoid sand clouds for a number of reasons: corporal damage by sand particles; predator avoidance; optomotor response to the contrast of cloud and background.

The difference in size of the fishing circles may have had the primary impact on the differences in catch between experimental and standard nets. However, the experimental nets were constructed so that the footropes swept the same area of the bottom, and therefore the difference in catch rates is most likely due to the differences in design of the tops of the nets.

Differences in catch rates between experimental and standard nets may also be linked to differences in dimensions of the codends. The codend in the standard net (50 meshes long) was smaller than that of both experimental nets (75 meshes long). Broadhurst and Kennelly (1996) demonstrated that differences in the circumference of codends in prawn trawls may alter selectivity by creating displacement and change in direction of water flow. This effect is believed to herd schools of fish into the anterior section of the codend, subsequently triggering an escape response towards the sides and top of the net. It is possible that a similar effect has occurred with the nets used in this study.

The specific reason why flatfish catches declined is not clear. We have rarely seen flatfish escape nets through top meshes, yet the differences in catch rates are substantial between the standard and both experimental designs. We theorize several possible mechanisms (outside of unidentified sources of bias) to explain the differences. Some fish were observed spilling out of the topless net during haulback. This possible source of loss, likely due to the absence of much of the top of the net, needs investigation and possible mediation through changes in haulback procedures, or use of “net-lockers”, a mesh panel that closes off the codend when towing stops, commonly used in Denmark and not used to our knowledge in the US.

A second potential loss of flatfish is through unmasked codend meshes. Field observations indicated that smaller fish tended to be associated with large catches. One possible reason for the capture of fish much smaller than the mesh size openings is that the openings are covered by cod, ocean pout, or other organisms that fill the codend, blocking escapement. It could be that design differences that reduce bycatch are allowing the codend to maintain its selectivity more so than if the codend was filled.

A third area of potential loss is along the wings of the trawls. Escape in this area may be most prevalent with the topless trawl, which had no top wing. Testing of a model topless net in a flume tank indicated that the wings tended to lean outward. Some evidence that the wings behaved similarly underwater was seen on underwater video. This leaning could lead flatfish and other fish to escape the net over the top of the wings. Further underwater observations of the fish capture process of these nets would aid in determining further modifications of the nets to reduce flatfish loss.

A fourth possible explanation is that the flatfish escaped upwards after perceiving the darkness of the cod end. This type of behavior has been observed for haddock and whiting and exploited through use of contrasting twine or a “black tunnel” (Glass and Wardle 1995). Changes in webbing, such as from normal diamond mesh to square mesh, change light penetration and may trigger an escape response by fish (Engås et al. 1989), although Madsen et al. (1997, 1998) found that color contrasts in codends did not affect cod. Flatfish may have charged upward just before the headrope (in the topless trawl) or through the large mesh (in the Ribas net). Further filming with the camera farther back in the net may provide some evidence for this explanation.

A final possible explanation for lower catch rates in the experimental nets is that the rigging of both experimental nets made them lighter, and they simply tended bottom less closely than the standard design. Although nets were not weighed, the removal of much of the top square in the topless net, and the reduction in mesh size in the Ribas design, probably reduced the mass of the net. In the absence of other adjustments, it seems logical to conclude that these nets were lighter. If the bottom was tended less closely, flatfish catches would likely be reduced.

The length-frequency comparisons provide some evidence to support one of these explanations. Results for both nets, and for all three species examined, show modes at larger sizes for the experimental nets, despite the use of knotless mesh in the standard nets and knotted mesh in the experimental nets. It seems unlikely that differences in behavior between different size fish within three different species using two different experimental designs could account for the observed differences. A mechanical effect, such as improved escapement through codend meshes due to reduced masking, seems to offer the simplest explanation. It cannot be ruled out, however, that if these nets are lighter on the bottom, they may select for larger fish.

The ANOVA results showed that net factor was significant for cod, yellowtail flounder above and below MLS, and winter flounder above and below MLS, indicating that the designs produced differences in catch. The vessel factor was also significant for all catch except kept yellowtail. “Vessel” was used in this analysis as a catch-all category, and encompasses seasonal effects, depth effects, and other factors that were conflated with the actual impact of the three vessels on catch. This difference in significance among species suggests that, for yellowtail, one or more of the environmental variables encompassed in “vessel” played less of a role in the variability of yellowtail catches than for others. Lastly, the lack of a vessel-net interaction in all comparisons allows the prediction of the impact of the net designs based on the net and vessel and discounts any synergistic effects of those two factors (Sokal and Rohlf 1995). The significance of the vessel term is common and to be expected; some vessels are more efficient at catching fish.

The specific mechanism or behavior that produces the reduction in cod and flatfish catches is undefined, but the reduction is definite. One possible application for these net designs is access to areas closed to protect cod. Preliminary results from this study were presented to the Plan Development Team of the Groundfish Committee of the NEFMC, and were accepted as adequate, but limited in demonstration to small boats during the day. Further work is planned to test these designs, at larger scale and during day and night, on larger vessels.

Great potential exists for such designs to gain industry acceptance if they can maintain efficient catches (especially for flatfish) through further modifications. In particular, square mesh panels are simple modifications that can be made by fishermen in response to legal changes in mesh size. This replacement serves as an economic alternative to replacing the entire trawl.

The loss of flatfish using these designs is not trivial. A typical conservative ex-vessel price for yellowtail flounder is over US$2.20/kg. Some compensation may be found in landing larger fish for larger prices, but this price differential is not reliable. Nevertheless, this loss may become acceptable to industry if access is allowed to areas that might otherwise be closed because of the status of cod stocks. Further, the reduction in efficiency may be a virtue because one stock of yellowtail flounder in these waters is in need of reductions in fishing effort. A net that catches little cod and less yellowtail flounder, while inefficient, may allow fishermen to reduce discards by controlling catch.

Decisions over these tradeoffs will need to be made by regulators if the designs are written into legislation, or by individual fishermen if the nets remain optional.

This study presents another example of positive results that arise through partnerships and cooperation between managers, fishermen and fishery scientists. This study responded to a clear need: access to fishing while protecting selected species. The origin of the designs was disparate: the Ribas design developed through fishing experience; the topless design was a product of the scientific community. The conduct of the experiment was a partnership of biologists designing the study and collecting data and fishermen constructing nets, finding suitable fishing grounds and quantities of fish. In sum, this study follows a model that is, was, and continues to be effective in the development of sustainable fishing gear and methods.

Acknowledgements

We appreciate the cooperation and patience of the F/Vs Blue Skies, Blue Ocean and Dolores Louise. Sea sampling under arduous conditions was conducted by Mark Szymanski, Rebecca Jones, Vincent Manfredi and Brian Kelly of DMF and Armista Frothinger. John Sheppard, Mark Szymanski, Bill Hoffman, Bob Glenn, Steve Correia, and Thomas Moth-Poulsen of DMF contributed greatly to the manuscript. Partial funding was provided by a grant awarded by the Northeast Consortium of Sea Grant Programs; and administered by Dr. Chris Glass of Manomet Center for Conservation Sciences. We are grateful to the staff of both of these organizations. Additional testing was performed under an Experimental Fishing Permit authorized by the Northeast Regional Office of the

National Marine Fisheries Service. This contribution is #6 from the Massachusetts Division of Marine Fisheries.

Literature cited

Boudreau, M. 1991. The performance of a horizontal split level trawl in the Gulf of St. Lawrence segregating cod from flatfish. Fish. Aquat. Sci. Tech., Ancona, April 1991. ICES, Copenhagen, Denmark.

Broadhurst, M.K., Kennelly, S.J. 1996. Effects of the circumference of codends and a new design of square-mesh panel in reducing unwanted bycatch in the New South Wales oceanic prawn-trawl fishery, Australia. Fish. Res. 27, 203 – 214.

Carr, H. A., Milliken, H. O. 1998. The use of video and acoustics to assess net performance and study fish behavior. Proceedings of the FIGEMOD International Workshop on Fishing Gear Measurement and Observation Devices, Nov. 30 - Dec. 4, 1998, Lorient, France. 8 p.

Engås, A., West, C.W. 1995. Development of a species-selective trawl for demersal gadoid fisheries. ICES C.M. 1995/B+G+H+J+K,1.

Engås, A., Isaksen, B., Valdemarsen, J.W. 1989. Escape behaviour of fish in codends in bottom trawl, 1985 – 1987. In: Carr, H.A. (Ed.) Proceedings of the Square Mesh Workshop, St. John’s, Newfoundland, 1989.

Glass, C.W., Wardle, C. S. 1995. Studies on the use of visual stimuli to control fish escape from codends. II. The effect of a black tunnel on the reaction behaviour of fish in otter trawl codends. Fish. Res. 23,165-174.

Larsen, R.B., Isaksen, B. 1993. Size selectivity of rigid sorting grids in bottom trawls for Atlantic cod Gadus morhua and haddock Melanogrammus aeglefinus. ICES Mar. Sci. Symp. 196, 178 – 182.

Lowry, N., Knudsen, L.H., Wileman, D. 1995. Selectivity in Baltic cod trawls with square mesh cod-end windows. ICES C.M. 1995/B,5.

Madsen, N., Moth-Poulsen, T., Lowry, N. 1997. Experiments with contrast colours and estimates of the selectivity in window codends fished in the Baltic Sea cod (Gadus morhua) fishery. ICES CM 1997/FF:01.

Madsen, N., Moth-Poulsen, T., Lowry, N. 1998. Selectivity experiments with window codends fished in the Baltic Sea cod (Gadus morhua) fishery. Fish. Res. 36(1998),1-14.

Main, J., Sangster, G.I. 1981. A study of the fish capture process in a bottom trawl by direct observations from a towed underwater vehicle. Scottish fisheries research report no. 23, 1981.

Main, J., Sangster, G.I. 1982. A study of multi-level bottom trawl for species separation using direct observation techniques. Scottish fisheries research report no. 26, 1982.

New England Fishery Management Council. 1999. Amendment 9 to the Northeast Multispecies Plan. Newburyport, MA.

Northeast Fishery Science Center, National Marine Fisheries Service. 2000. Status of the Fishery Resources off the Northeastern United States. NOAA Tech. Mem. NMFS-NE-115.

Ozbilgin, H., Wardle, C.S. 2002. Effect of seasonal temperature changes on the escape behaviour of haddock, Melanogrammus aeglefinus, from the codend. Fish. Res. 58,323-331.

Robertson, J.H.B. 1993. Design and fitting of square mesh windows in whitefish and Prawn trawls and seine nets. Scottish Office Agriculture and Fisheries Dept. Scottish fisheries info. pamphlet No. 20.

Sokal, R.R., Rohlf, F.J. 1995. Biometry. W.H. Freeman and Co., New York.

Sprent, P. 1989. Applied Nonparametric Statistical Methods. Chapman and Hall, New York.

Suuronen, P., Lehtonen, E., Tschernij, V., Larsson, P.-O. 1995. Skin injury and mortality of Baltic cod escaping from trawl codends equipped with exit windows. ICES C.M. 1995/B,8.

Thomsen, B. 1993. Selective flatfish trawling. ICES Mar. Sci. Symp. 196,161 – 164.

Valdermarsen, J.W., Engås, A., Isaksen, B. 1985. Vertical entrance into a trawl of Barents Sea gadoids as studied with a two-level fish trawl. ICES C.M. 1985/B,46.

van Marlen, B. 1993. Research on improving the species selectivity of bottom trawls in the Netherlands. ICES Mar. Sci. Symp., 196, 165 – 169.

Wardle, C.S. 1986. Fish behaviour and fishing gear. In: Pitcher, T.J., (Ed.) Behaviour of Teleost Fishes. Chapman and Hall, pp 609-643.

Wardle, C.S. 1987. Investigating the behaviour of fish during capture. In: Developments in Fisheries Research in Scotland. R.S. Bailey and B.B. Parrish (eds.) Fishing News Books, pp 139-155.

Wileman, D.A. 1995. Review of the progress made in Denmark in the development of species selective gears. ICES C.M. 1995/B+G+H+J+K,2.

Wileman, D.A., Ferro, R.S.T., Fonteyne, R., Millar, R.B. 1996. Manual of methods of measuring the selectivity of towed fishing gears. ICES Coop. Res. Rep. No. 215, Copenhagen.

Table 1: Fishing log of experimental tows included in analysis. Trip ID is a unique identifier for each fishing trip. For each trip, tows were numbered sequentially starting with 1. The numbers under net type show which tows tested a particular net for a given trip.

		Net Type		
Date	**Trip ID**	**Standard**	**Ribas**	**Topless**
12/19/2000	MSC01	3, 6	4, 5	
5/1/2001	AF0101	2, 5	3, 4	
5/2/2001	AF0201	3, 4	2, 5	
5/17/2001	AF0301	1, 4		2, 3
5/21/2001	AF0501	2, 3		1, 4
5/25/2001	AF0601	2, 3		1, 4
5/26/2001	AF0701	2, 3		1, 4
6/4/2001	MS0201	1, 4		2, 3
6/5/2001	MIKE P.	1, 4		2, 3
6/7/2001	AF1101	2, 3	1, 4	
6/8/2001	AF1201	2, 3	1, 4	
4/4/2002	JS04	2, 3		1, 4
4/5/2002	JS05	2, 3	1, 4	
4/7/2002	JS06	1, 4	2, 3	
4/15/2002	BK1	1, 4		2, 3
4/15/2002	MS01	1, 5	2, 4	
4/16/2002	BK2	2, 3		1, 4
4/16/2002	MS02	2, 3	1, 4	
4/17/2002	BK3	3, 4	2, 5	
4/17/2002	MS03	2, 3, 6		1, 4, 5
4/18/2002	BK4	2, 3	1, 4	
4/18/2002	MS04	1, 4		2, 3
4/25/2002	VM1	1	2	
4/25/2002	MS06	1, 4		2, 3
5/20/2002	VM2	1, 4	2, 3	
5/20/2002	MS07	1, 4		2, 3
5/21/2002	VM3	2, 3	1, 4	
5/21/2002	MS08	2, 3		1, 4
5/22/2002	VM4	2, 3		1, 4
5/22/2002	MS09	2, 5	1, 6	
5/28/2002	BK5	1, 4, 5		2, 3, 6
5/28/2002	MS10	2, 5	3, 4	
5/29/2002	VM6	2, 3		1, 4
5/29/2002	MS11	1, 4, 5	2, 3, 6	

Table 2: Catch rates (kg/hr) of Atlantic cod, yellowtail flounder, and winter flounder. Significances were determined using paired-t tests on log-transformed data. Reductions were calculated using the standard catch as a starting point.

	Average Catch Rates (kg/hr)			
34 Pairs	**Standard**	**Ribas**	**% Reduction**	**Sign. (2-tailed)**
Atl. Cod	141.4	40.3	71.5%	0.0001
Yellowtail Fl.				
> MLS	155.8	97.1	37.7%	0.0006
< MLS	36.5	9.2	74.8%	0.0000
Winter Fl.				
> MLS	35.5	15.7	55.7%	0.0001
< MLS	9.3	1.7	82.2%	0.0000
36 Pairs	**Standard**	**Topless**	**% Reduction**	**Sign. (2-tailed)**
Atl. Cod	120.9	15.9	86.9%	0.0000
Yellowtail Fl.				
> MLS	144.9	98.6	32.0%	0.0002
< MLS	28.7	5.4	81.2%	0.0000
Winter Fl.				
> MLS	37.5	20.8	44.7%	0.0000
< MLS	7.4	2.9	60.6%	0.0000

Table 3: Reactions of cod and flounders in footage of the experimental nets collected using underwater cameras.

				# of Headrope Interactions		
Date	**Net Type**	**Tape Length (min)**	**Species**	**Over**	**Under**	**Through Mesh**
12/4/00	Ribas Net	55	Cod	15	53	0
12/4/00	Ribas Net	49	Cod	59	108	2
1/5/01	Topless Net	60	Cod	74	57	1
1/5/01	Topless Net	28	Cod	117	52	0

				# of Footrope Interactions		
Date	**Net Type**	**Tape Length (min)**	**Species**	**In Net**	**Under Net**	**Over Headrope**
12/4/00	Ribas Net	55	Flounders	119	4	0
12/4/00	Ribas Net	49	Flounders	44	1	0
1/5/01	Topless Net	60	Flounders	65	0	8
1/5/01	Topless Net	28	Flounders	10	0	0

Figure 1: Schematic of flatfish trawl net used by the Massachusetts otter trawl fleet and used as the standard net in this study.

Figure 2: Schematic of the "Ribas" net designed by Captain Luis Ribas, based on the standard net design. The top of the net (left side) is constructed mostly of 20.3 cm (8 in) square mesh.

Figure 3: Schematic of the Topless trawl net modeled after a design from the Faroe Islands. The top half of the net (left side) is greatly reduced, lengthening the headrope.

Figure 4: Locations of the beginning of all experimental tows included in this study. The inset shows the NE coast of United States.

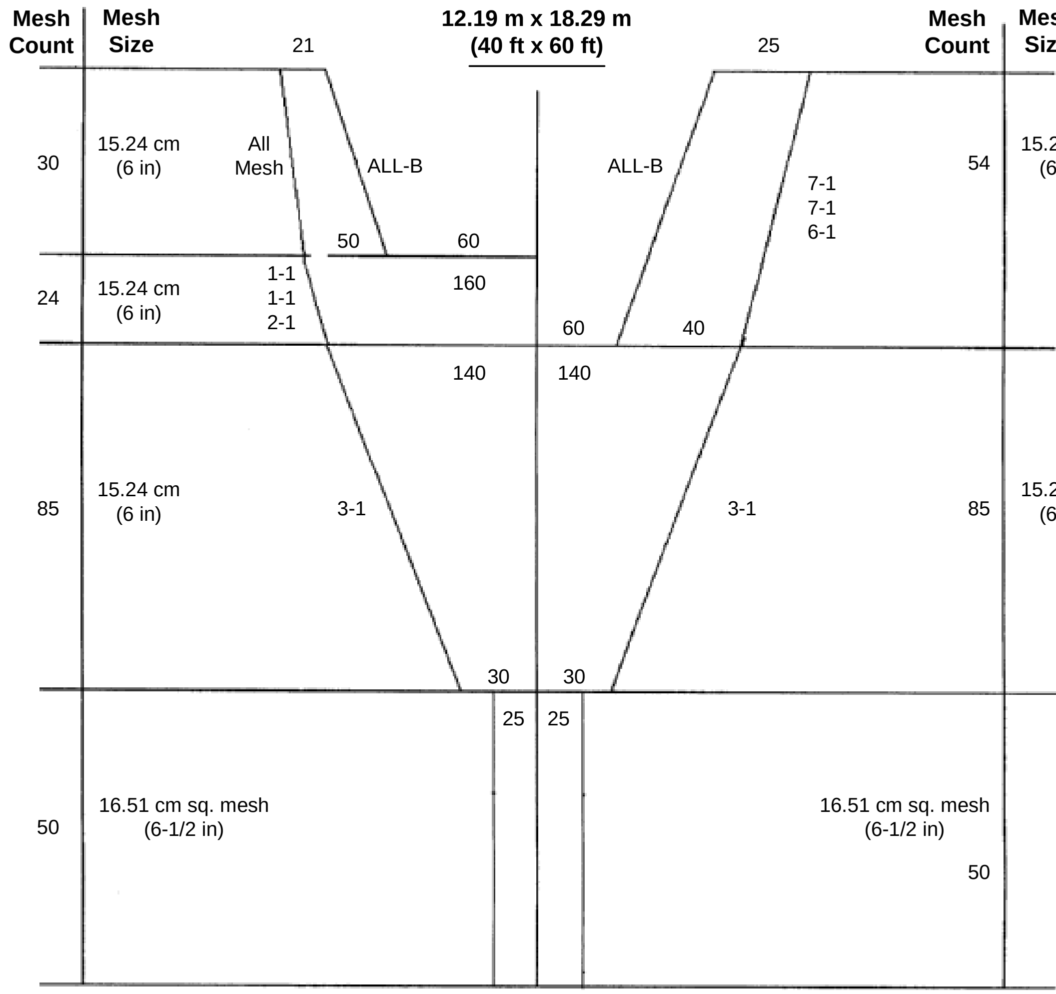
Figure 5: A (top) illustrates pairs of transformed catch rates for cod for comparisons of Ribas (solid diamonds) and topless (open squares) nets to the standard nets. A line illustrating equal catch is also included. B illustrates pairs of transformed catch rates for yellowtail flounder above MLS.

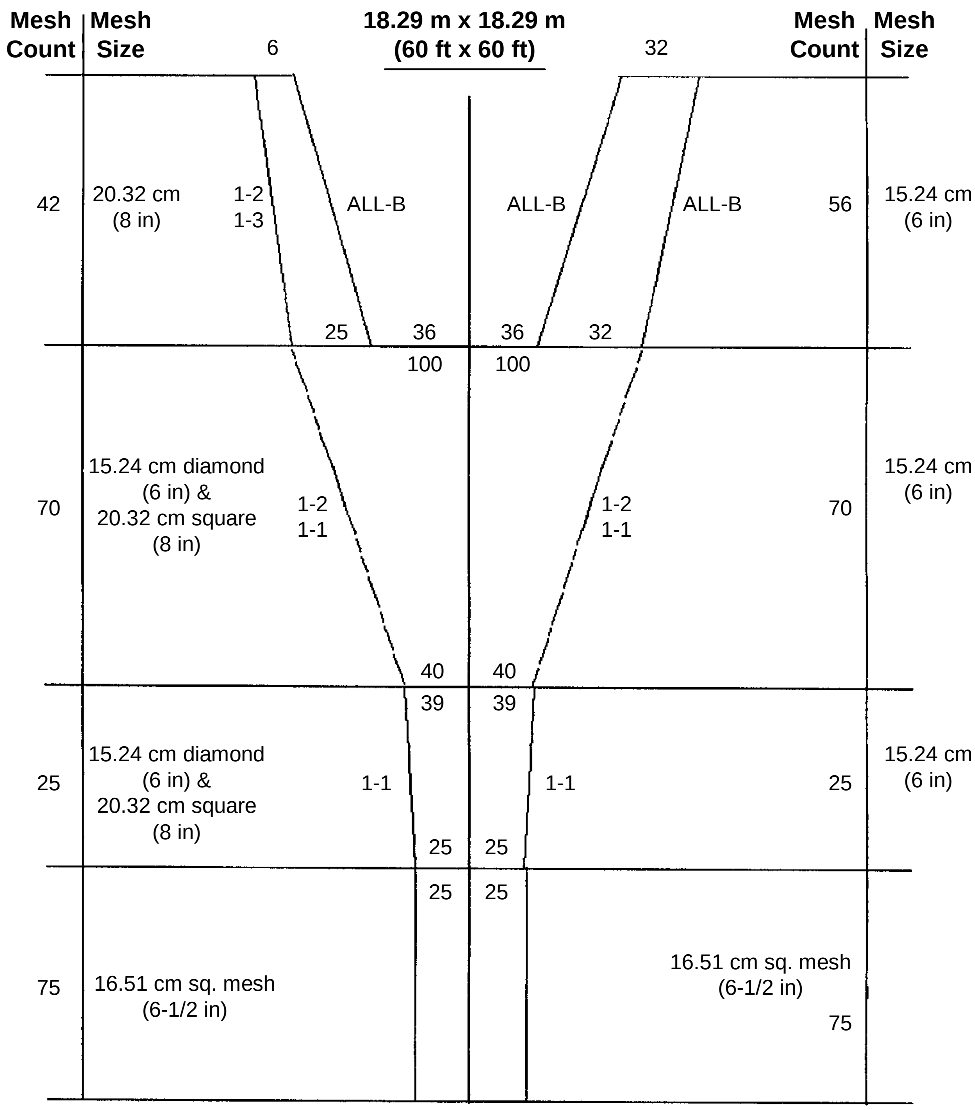
Figure 6: A (top) illustrates pairs of transformed catch rates for yellowtail flounder below MLS for comparisons of Ribas (solid diamonds) and topless (open squares) nets to the standard nets. A line illustrating equal catch is also included. B illustrates pairs of transformed catch rates for winter flounder above MLS.

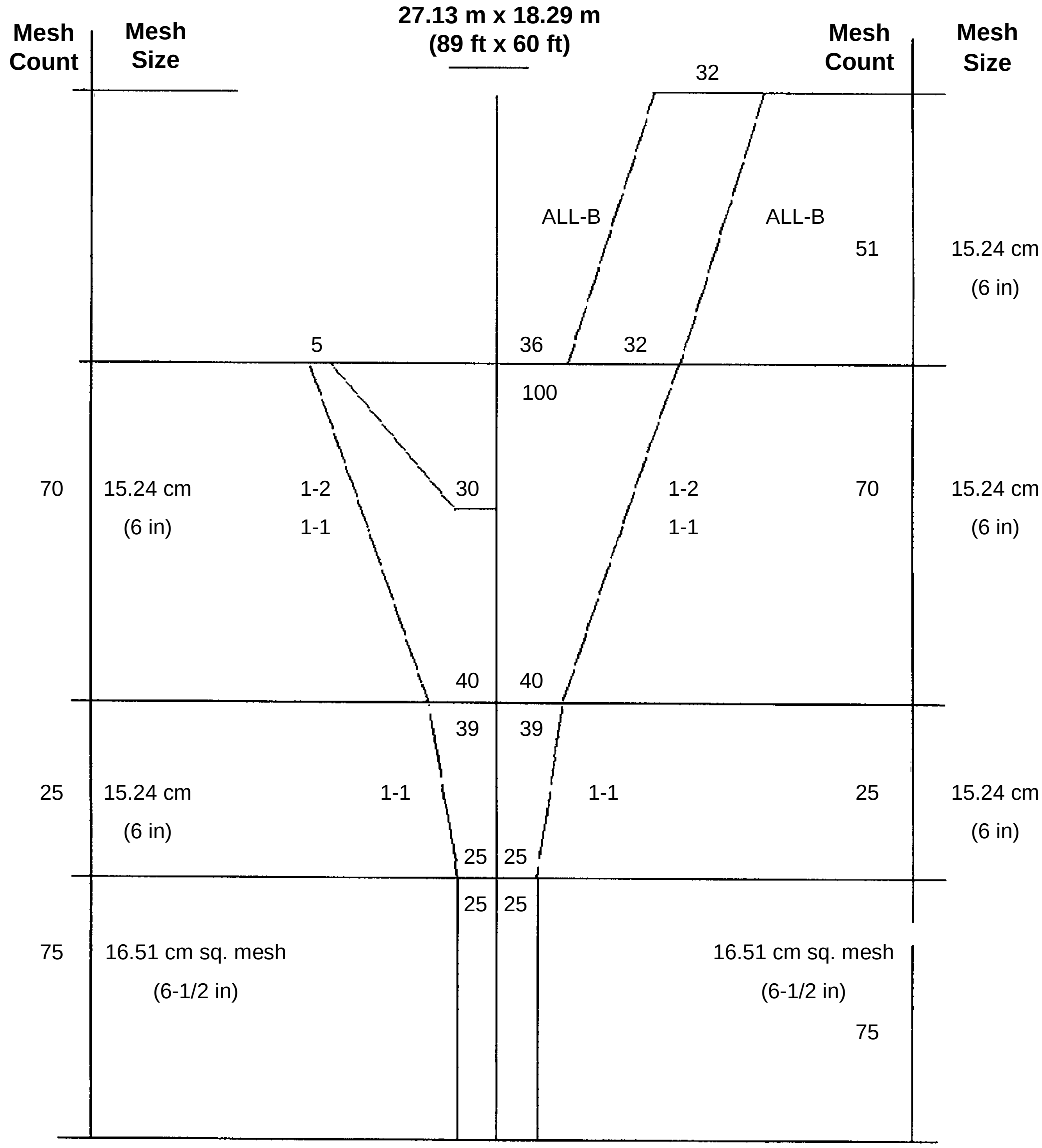
Figure 7: A (top) compares total lengths of cod caught during paired testing using the Ribas net and the standard net. B (bottom) compares lengths caught during paired testing of the Topless net and the standard net. Subsamples were extrapolated to the entire catch when necessary. N is the total extrapolated number of individuals. MLS = minimum landing size during testing.

Figure 8: A (top) compares total lengths of yellowtail flounder caught during paired testing using the Ribas net and the standard net. B (bottom) compares lengths caught during paired testing of the Topless net and the standard net. Subsamples were extrapolated to the entire catch when necessary. N is the total extrapolated number of individuals. MLS = minimum landing size during testing.

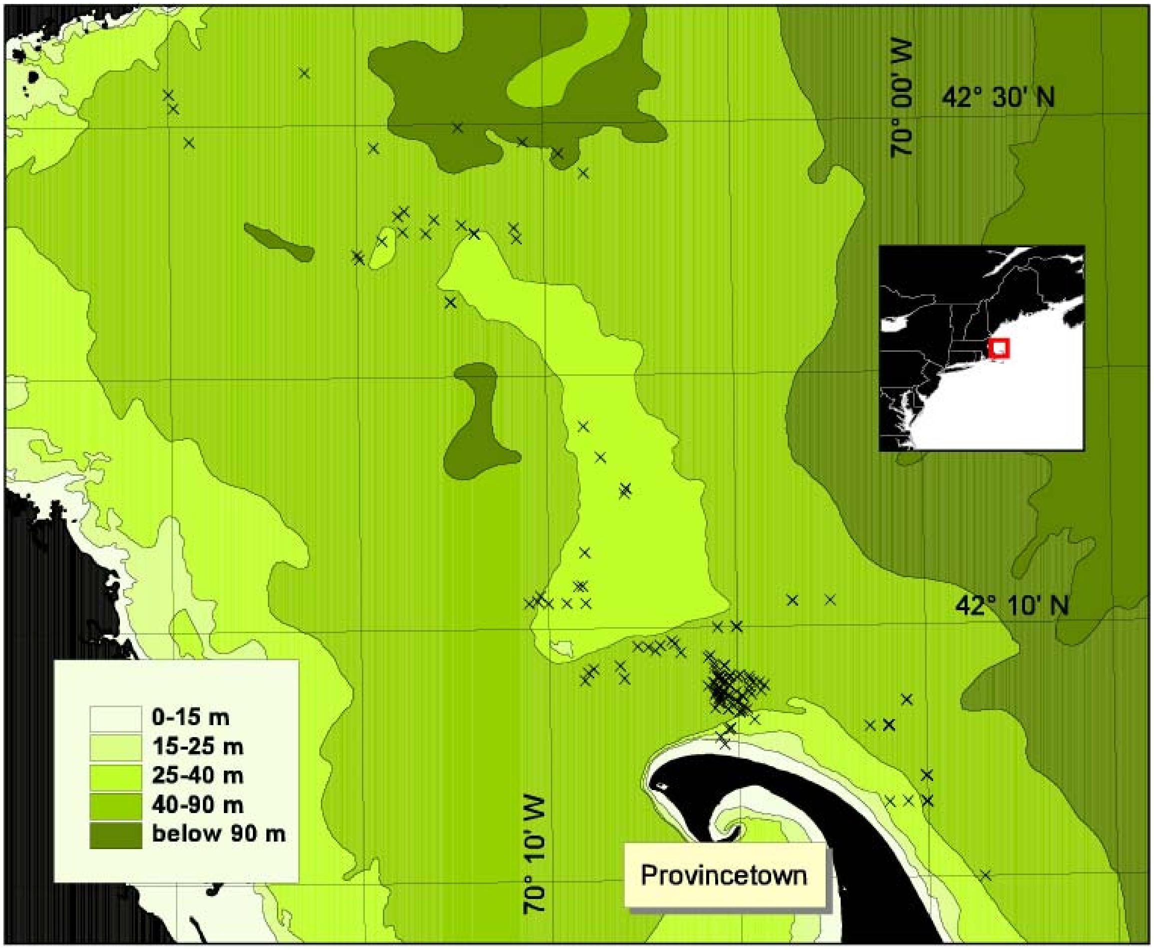
Figure 9: A (top) compares total lengths of winter flounder caught during paired testing using the Ribas net and the standard net. B (bottom) compares lengths caught during paired testing of the Topless net and the standard net. Subsamples were extrapolated to the entire catch when necessary. N is the total extrapolated number of individuals. MLS = minimum landing size during testing.


Mesh Count
Mesh Size
21
12.19 m x 18.29 m
(40 ft x 60 ft)
25
Mesh Count
Mesh Size
30
15.24 cm
(6 in)
All
Mesh
ALL-B
ALL-B
7-1
7-1
6-1
54
15.24 cm
(6 in)
50
60
24
15.24 cm
(6 in)
1-1
1-1
2-1
160
60
40
140
140
85
15.24 cm
(6 in)
3-1
3-1
85
15.24 cm
(6 in)
30
30
25
25
50
16.51 cm sq. mesh
(6-1/2 in)
16.51 cm sq. mesh
(6-1/2 in)
50

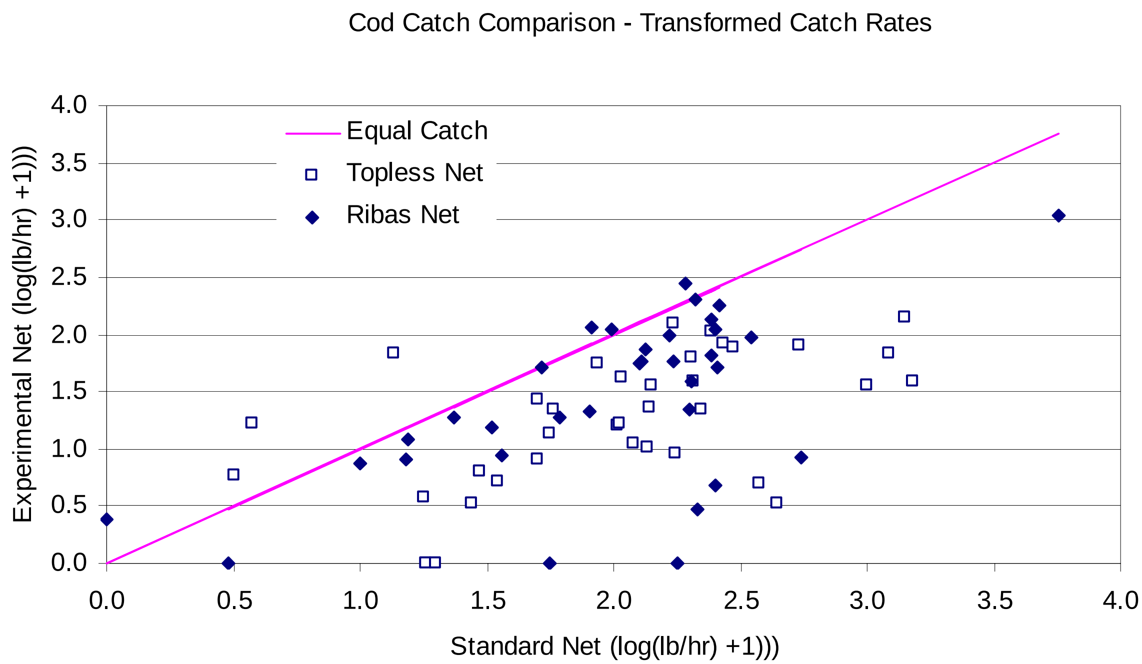

Mesh Count
Mesh Size
6
18.29 m x 18.29 m
(60 ft x 60 ft)
32
Mesh Count
Mesh Size
42
20.32 cm
(8 in)
1-2
1-3
ALL-B
ALL-B
ALL-B
56
15.24 cm
(6 in)
25
36
36
32
100
100
15.24 cm diamond
(6 in) &
20.32 cm square
(8 in)
70
1-2
1-1
1-2
1-1
70
15.24 cm
(6 in)
40
40
39
39
25
15.24 cm diamond
(6 in) &
20.32 cm square
(8 in)
1-1
1-1
25
15.24 cm
(6 in)
25
25
25
25
75
16.51 cm sq. mesh
(6-1/2 in)
16.51 cm sq. mesh
(6-1/2 in)
75

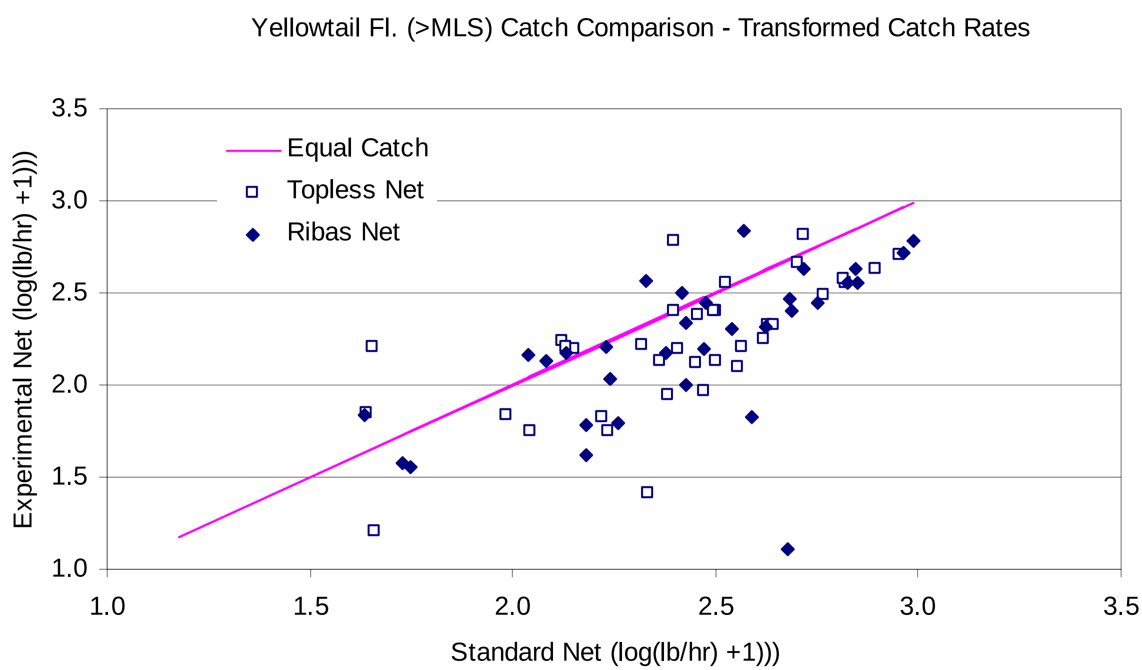


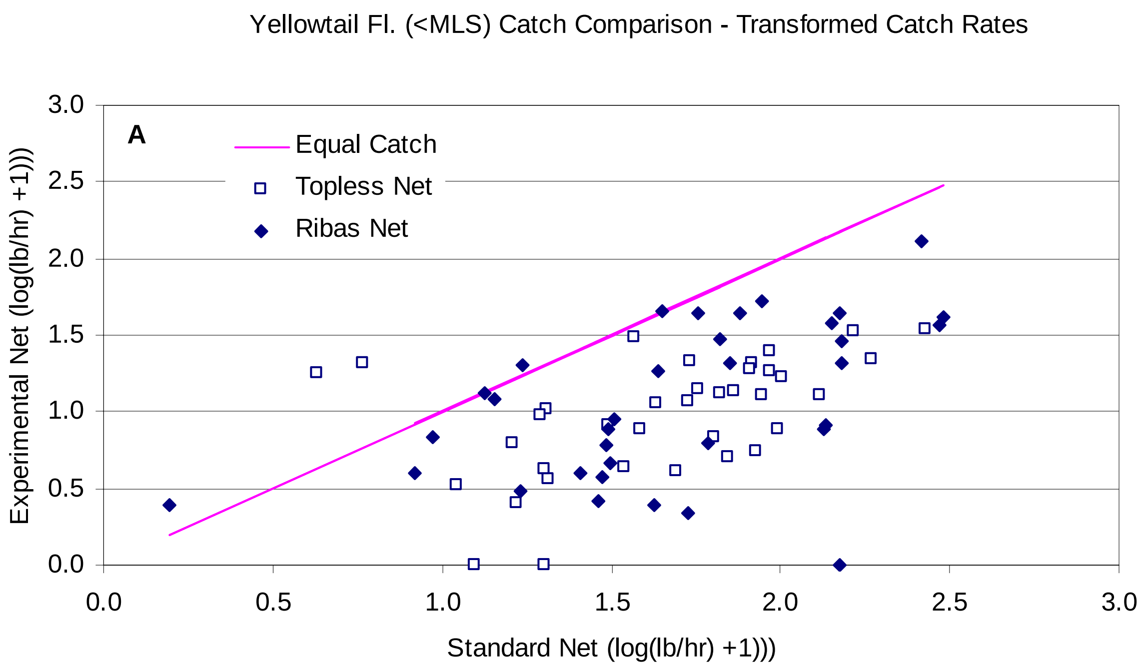
Mesh Count
Mesh Size
27.13 m x 18.29 m
(89 ft x 60 ft)
Mesh Count
Mesh Size
32
ALL-B
ALL-B
51
15.24 cm
(6 in)
5
36
32
100
70
15.24 cm
(6 in)
1-2
1-1
30
1-2
1-1
70
15.24 cm
(6 in)
40
40
39
39
25
15.24 cm
(6 in)
1-1
1-1
25
15.24 cm
(6 in)
25
25
25
25
75
16.51 cm sq. mesh
(6-1/2 in)
16.51 cm sq. mesh
(6-1/2 in)
75

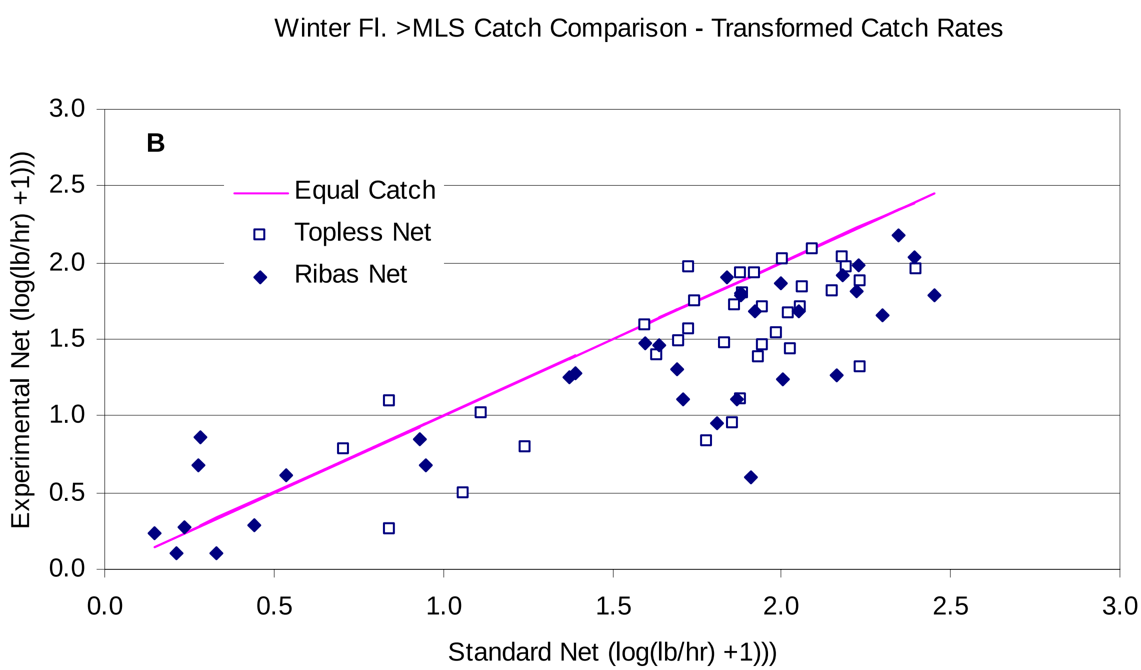


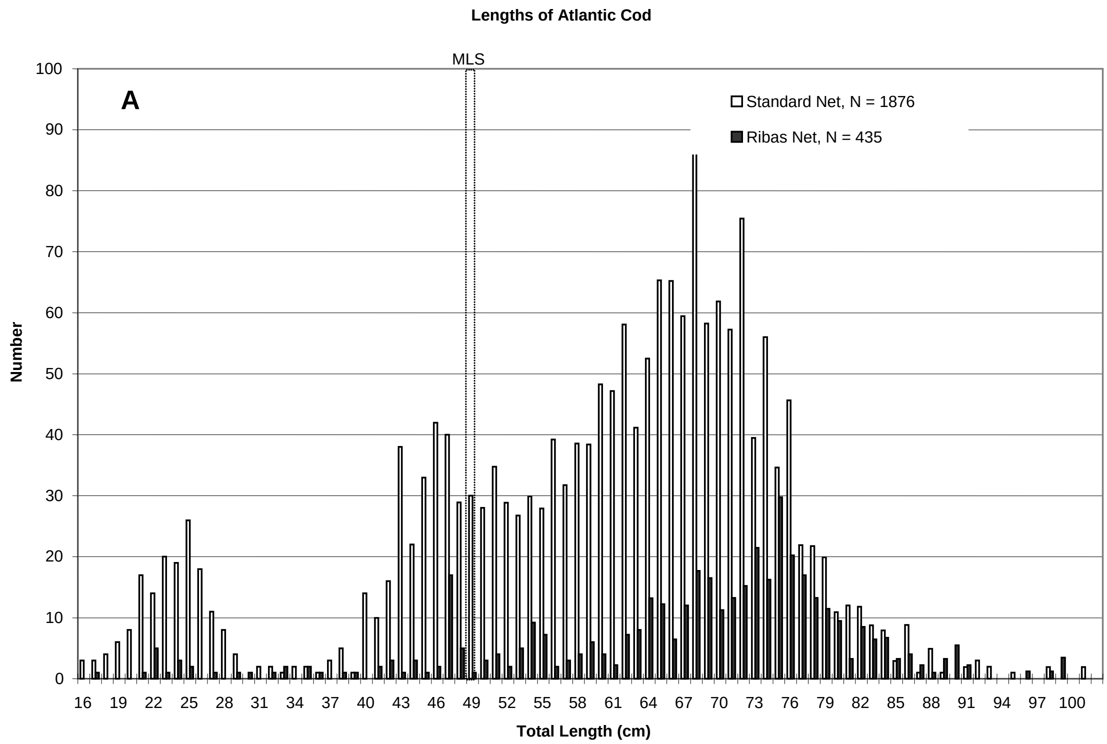
70° 00' W
42° 30' N
42° 10' N
70° 10' W
Provincetown
0-15 m
15-25 m
25-40 m
40-90 m
below 90 m


Cod Catch Comparison - Transformed Catch Rates
Equal Catch
Topless Net
Ribas Net
Experimental Net (log(lb/hr) +1)))
Standard Net (log(lb/hr) +1)))
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

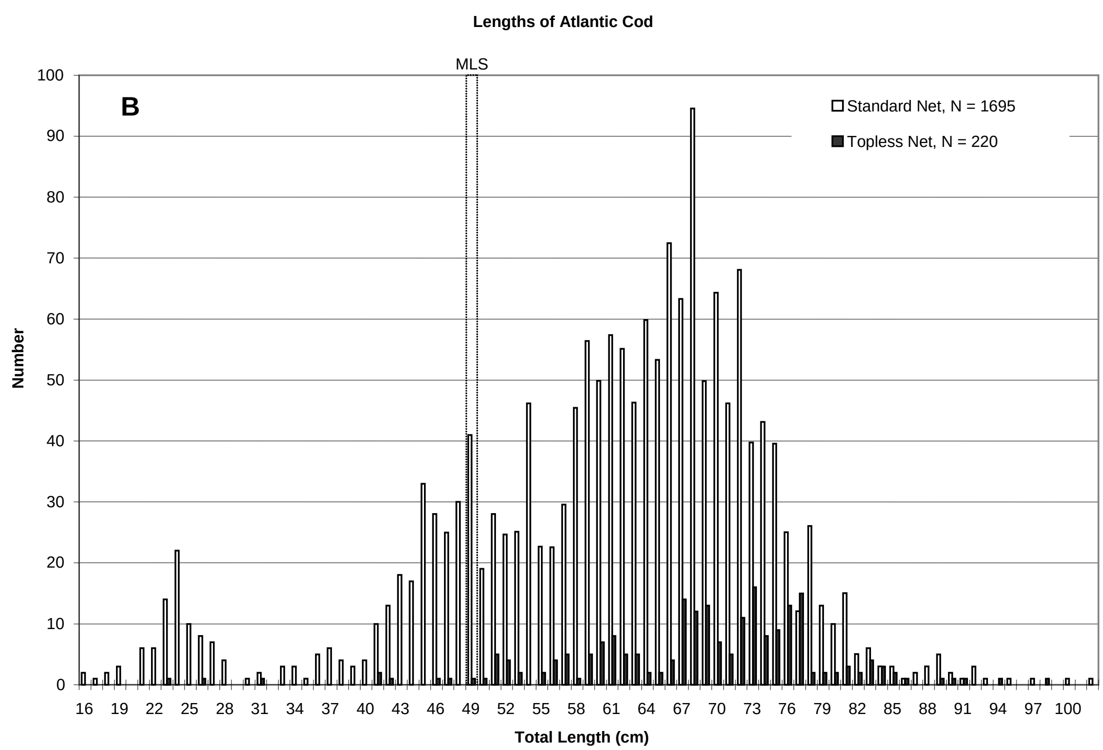

Yellowtail Fl. (>MLS) Catch Comparison - Transformed Catch Rates
Equal Catch
Topless Net
Ribas Net
Experimental Net (log(lb/hr) +1)))
Standard Net (log(lb/hr) +1)))
1.0
1.5
2.0
2.5
3.0
3.5


Yellowtail Fl. (<MLS) Catch Comparison - Transformed Catch Rates
A
Equal Catch
Topless Net
Ribas Net
Experimental Net (log(lb/hr) +1)))
Standard Net (log(lb/hr) +1)))
3.0
2.5
2.0
1.5
1.0
0.5
0.0

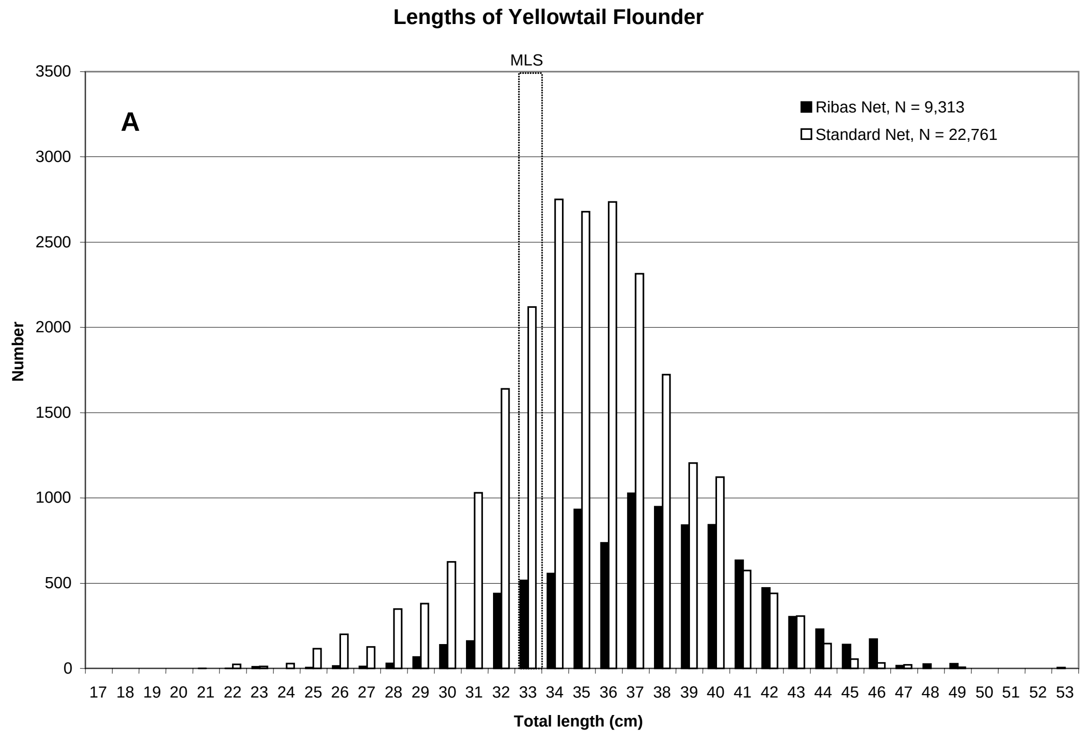

Winter Fl. >MLS Catch Comparison - Transformed Catch Rates
B
Equal Catch
Topless Net
Ribas Net
Experimental Net (log(lb/hr) +1)))
Standard Net (log(lb/hr) +1)))
3.0
2.5
2.0
1.5
1.0
0.5
0.0

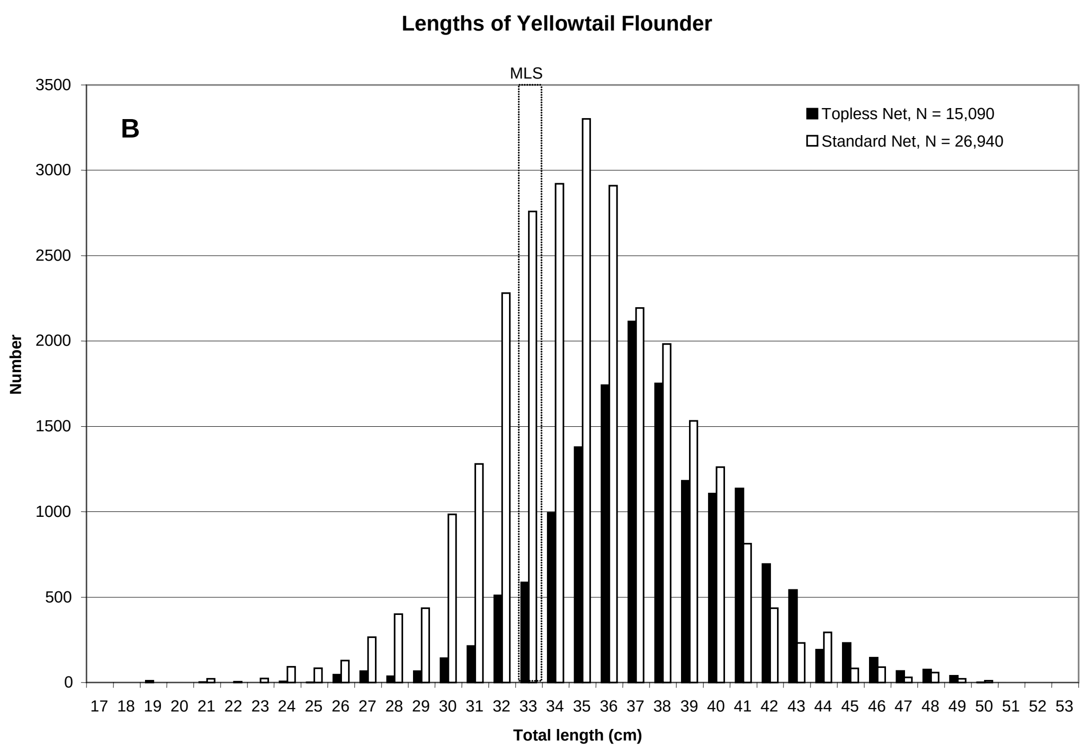


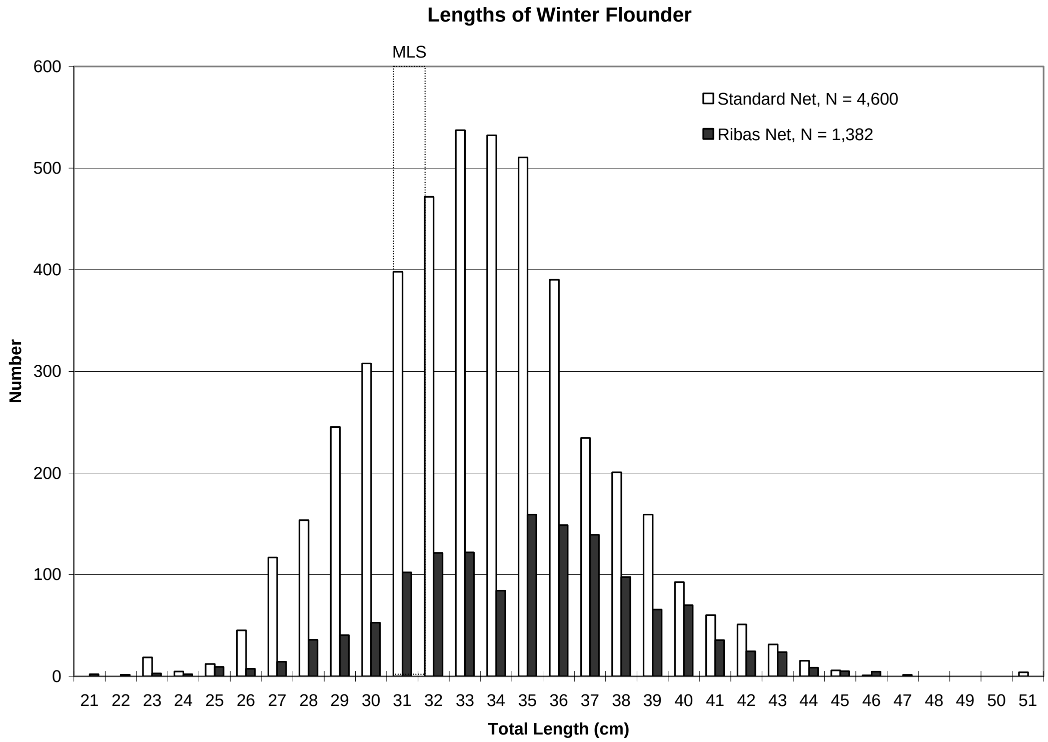
Lengths of Atlantic Cod
MLS
A
Standard Net, N = 1876
Ribas Net, N = 435
Number
Total Length (cm)

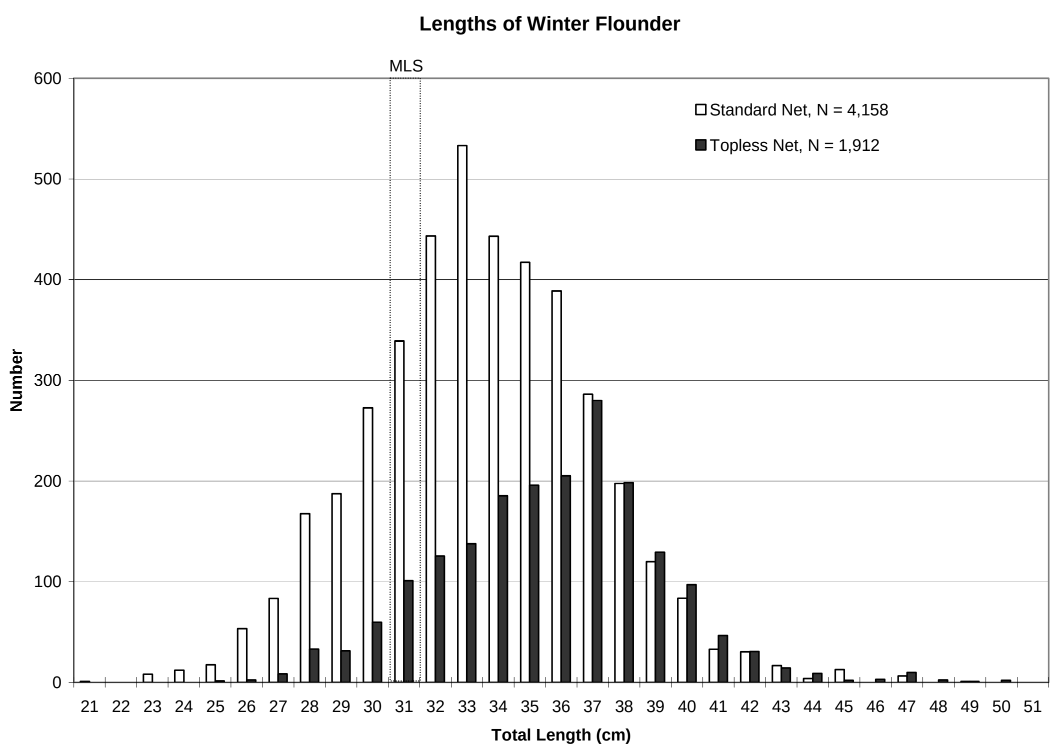


Lengths of Atlantic Cod
MLS
B
Standard Net, N = 1695
Topless Net, N = 220
Number
Total Length (cm)


Lengths of Yellowtail Flounder
MLS
A
Ribas Net, N = 9,313
Standard Net, N = 22,761
Number
3500
3000
2500
2000
1500
1000
500
0
17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53
Total length (cm)


Lengths of Yellowtail Flounder
MLS
B
Topless Net, N = 15,090
Standard Net, N = 26,940
Number
3500
3000
2500
2000
1500
1000
500
0
17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53
Total length (cm)


Lengths of Winter Flounder
MLS
Standard Net, N = 4,600
Ribas Net, N = 1,382
Number
0
100
200
300
400
500
600
21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51
Total Length (cm)


Lengths of Winter Flounder
MLS
Standard Net, N = 4,158
Topless Net, N = 1,912
Number
0
100
200
300
400
500
600
21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51
Total Length (cm)